Original Research

A Comparison of Three Dietary Pattern Indexes for Predicting Biomarkers of Diet and Disease

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Key words: diet quality, dietary indexes, biomarkers, BMI, blood pressure, NHANES III, components of variance

Objective: Examination of dietary indexes in association with objective biomarkers of dietary intake and chronic disease risk is an important step in their validation. We compared three dietary pattern indexes—Healthy Eating Index (HEI), Recommended Foods Score (RFS-24 hour recall), and Dietary Diversity Score for recommended foods (DDS-R)—for their ability to predict biomarkers of dietary intake, obesity, cardiovascular disease, and diabetes.

Methods: We used dietary and laboratory data from the third National Health and Nutrition Examination Survey to study these associations in 8719 disease-free adults aged ≥20 y. The HEI, developed by the USDA, was a sum of scores on consideration of ten individual components; the RFS was a sum of all recommended foods (lean meat, poultry and fish, whole grains, fruits and juices, low-fat dairy, and vegetables) mentioned in the recall; the DDS-R examined whether or not a recommended food was mentioned from each of the five major food groups. The independent association of the dietary pattern indexes with body mass index (BMI), blood pressure, and serum concentrations of several biomarkers were examined using regression methods to adjust for multiple covariates.

Results: All indexes were strong independent positive predictors of serum concentrations of vitamin C, E, folate, and all carotenoids ($p \leq 0.00001$), except lycopene, and were negative predictors of BMI, serum homocysteine, C-reactive protein, plasma glucose, and hemoglobin A1C ($p < 0.05$). The RFS and DDS-R were inversely associated with blood pressure and serum cholesterol ($p \leq 0.03$).

Conclusions: The RFS and DDS-R performed as well or better than the HEI for predicting serum concentration of nutrients and biomarkers of disease risk.

INTRODUCTION

With increasing recognition of multidimensional nature of diets consumed by free living individuals, dietary patterns have emerged as an alternative or an adjunct to the traditional approach of using single nutrients or food groups as exposures for examining the diet and health associations [1–5]. Recently, both observational studies and intervention trials have provided evidence in support of the pattern based approach to dietary exposures in relation to health [1]. Intuitively, dietary patterns may modify the risk of disease through established risk-factors of disease, and also by relating to intake of micronutrients. Thus, evaluation of dietary patterns for predicting objective biomarkers of dietary intake and risk of chronic diseases is an important step in their validation as predictors of health outcome. In this study we compare three indexes—the Healthy Eating Index of the USDA, the Recommended Foods Score (RFS), and the Dietary Diversity Score (DDS) for their ability to predict biomarkers. The HEI was developed by the USDA to monitor diet quality of the US population [6]. We previously developed the RFS and the DDS which were shown to relate to risk of mortality [7–9].

METHODS

This study used data from the third National Health and Nutrition Examination Survey (NHANES III), 1988–1994. The

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NHANES III was a multistage stratified probability sample of the non-institutionalized, civilian US population, aged 2 months and over [10]. The survey was conducted by the National Center for Health Statistics (NCHS), and included administration of a questionnaire at home and a full medical exam along with a battery of tests in a special mobile examination center (MEC). Demographic and medical history information was obtained during the household interview. The MEC exam included a physical and dental exam, dietary interview, body measurements, and collection of blood and urine samples. Body weight and height were measured using standardized procedures in the MEC.

Dietary Assessment Method

A 24-hour dietary recall was collected by a trained dietary interviewer in a MEC interview using an automated, microcomputer based interview and coding system [10]. The type and amount of foods consumed were recalled using aids such as abstract food models, special charts, measuring cups, and rulers to help in quantifying the amounts consumed. Special probes were used to help recall commonly forgotten items such as condiments, accompaniments, fast foods, and alcoholic beverages, etc.

As part of a sub-study within NHANES III, a nonrandom subsample of approximately 5% of those who completed a visit to the MEC were invited back for a second visit [11]. During this repeat visit, another dietary recall, using methods similar to the first one, was also obtained.

Analytic Sample

All adults aged 20 y and over with a complete and reliable dietary recall (as determined by NCHS) were eligible for inclusion (n = 15,979). We excluded respondents stating that food intake on recalled day was "much less" or "much more" than usual (n = 2245), women who were pregnant (n = 282) or nursing (n = 91), and those missing information on body weight (n = 33) or height (n = 16). Finally, respondents who reported that they were informed by a doctor that they had diabetes, hypertension, or history of heart attack (or reported use of medications for hypertension, hyperglycemia, or hyperlipidemia) were excluded (n = 4681)—leaving an analytic sample of 8719. Some respondents were in more than one exclusion category.

From the second exam subsample, a reliable second recall was available for 617 respondents in our analytic sample who also provided a reliable first recall.

Dietary Indexes

From the 24-hour recall data, we derived three dietary indexes: the Healthy Eating Index (HEI), the Recommended Foods Score (RFS), and a Dietary Diversity Score (DDS-R).

Healthy Eating Index (HEI). The HEI was developed by the USDA to assess concordance with dietary guidance and to monitor changes in diet quality of the US population [6]. The HEI comprises ten components (saturated fat intake, total fat intake, cholesterol intake, sodium intake, grain intake, fruit intake, dairy intake, meat intake, vegetable intake, and dietary variety) that contribute 10 points each to the maximum possible score of 100. The food group serving criteria are gender and age specific. The HEI available on the NHANES public release data file was used for examination of association with biomarkers [12].

The HEI is not available for the second recall subsample. Because of our interest in exploring components of variance in the HEI using the second recall data, we computed the HEI following the methods described in the NHANES III Healthy Eating Index documentation [12] for both days 1 and 2. To enable this computation, we used the NHANES III pyramid servings data base (PSDB) [13]. All components except the dietary variety score could be replicated and were highly correlated with those available on the data file (with Pearson's correlation coefficients ranging from >0.91–0.99). According to the NHANES III documentation, the HEI variety score is commodity based, ingredients of foods reported contribute to the variety score, and different forms of a food item are collapsed, but excludes ingredients in "fats, sweets, seasonings, and similar foods". We modified the variety component to consist of all unique food codes within the energy-dense food groups (fruit, vegetable, meat/and alternates, grains, and dairy) if mentioned in amounts that were at least half serving of a food as defined in PSDB. Mixed dishes contributed as many points as component food groups. The variety component score computed by us and that available in the NHANES III data file were highly correlated (r = 0.72). The overall HEI score computed by us (labeled HEI-C) and that available in the data file were highly correlated (r = 0.96).

Recommended Foods Score (RFS). We previously developed the recommended foods score using food frequency data in the Breast Cancer Detection and Demonstration Project cohort [7]. Because the HEI in the NHANES III was computed from the 24-hour recall data, to ensure comparability, we adapted the original RFS computed from the food frequency questionnaire to 24-hour recall. Individual foods reported in the recall were examined and grouped into the recommended category. Out of a total of 4263 foods reported by the analytic sample, (1439) or 38% met the criteria for recommended foods. Foods considered to be recommended (low fat dairy; lean meats, poultry, fish, and alternatives; low fat whole grains such as whole wheat breads and cereals; all fruits and juices; all vegetables that were not fried, pickled, or creamed) in each recall were summed. Mixed dishes were considered recommended if their fat content was <35% of energy, and contributed one point to the overall score. The foods were counted only if they were consumed in at least a minimum amount—the minimum amount threshold was 15 g for non-beverages, and 30

Table 1. Least Square Mean ± SE[1] of Each Dietary Pattern Index by Socioeconomic and Life-Habit Variables, Disease Free Adults Aged ≥20 y, NHANES III, 1988–1994

	n	HEI	RFS	DDS-R
All	8719	63.75 ± 0.32	3.97 ± 0.06	2.44 ± 0.03
Men	4302	62.68 ± 0.40	3.95 ± 0.08	2.30 ± 0.03
Women	4358	64.77 ± 0.30	3.98 ± 0.06	2.82 ± 0.03
Age <50 y	5896	62.27 ± 0.33	3.64 ± 0.05	2.41 ± 0.04
Aged ≥50 y	2764	67.99 ± 0.39	4.89 ± 0.08	2.46 ± 0.03
Race/Ethnicity				
Non-Hispanic White	3582	63.70 ± 0.35	4.64 ± 0.06	2.47 ± 0.02
Non-Hispanic Black	2146	60.59 ± 0.39	3.23 ± 0.07	2.04 ± 0.03
Mexican-American	2563	66.30 ± 0.50	4.24 ± 0.09	2.59 ± 0.04
Other	369	66.05 ± 0.71	3.92 ± 0.15	2.46 ± 0.09
Education (years)				
<12 y	3154	61.29 ± 0.45	3.30 ± 0.08	2.16 ± 0.05
12 y	2746	62.88 ± 0.29	3.65 ± 0.06	2.29 ± 0.03
>12 y	2760	65.54 ± 0.43	4.51 ± 0.09	2.67 ± 0.03
Smoking Status				
Never smoker	4316	65.25 ± 0.42	4.30 ± 0.03	2.59 ± 0.03
Former smoker	1942	65.10 ± 0.41	4.29 ± 0.09	2.62 ± 0.04
Current smoker	2402	60.33 ± 0.51	3.19 ± 0.07	2.05 ± 0.04
Alcohol intake (drinks/day)				
None	3997	63.24 ± 0.35	3.88 ± 0.67	2.43 ± 0.04
≤1	4078	64.13 ± 0.33	4.04 ± 0.08	2.46 ± 0.03
>1 to ≤2	412	64.20 ± 1.02	4.03 ± 0.21	2.34 ± 0.07
>2	173	62.77 ± 1.21	3.81 ± 0.30	2.36 ± 0.11
Body mass index (kg/m^2)				
<25	3949	64.30 ± 0.36	4.08 ± 0.06	2.48 ± 0.03
25–<30	2998	63.89 ± 0.31	4.00 ± 0.06	2.48 ± 0.02
≥30	1713	61.79 ± 0.56	3.55 ± 0.12	2.24 ± 0.05
Level of recreational physical activity/week				
None	3949	62.47 ± 0.47	3.56 ± 0.09	2.27 ± 0.04
1–2 times/week	2998	64.01 ± 0.29	4.05 ± 0.05	2.47 ± 0.03
>2 times/week	1713	65.06 ± 1.41	4.30 ± 0.35	2.63 ± 0.12
Model R^2		0.13	0.14	0.13

[1] Least square means from regression models with each dietary pattern variable as a continuous outcome and all variables in the table as independent variables. Thus, the mean for a variable is adjusted for all other independent variable in the model. All variables except alcohol intake were significant predictors of HEI, RFS, and DDS-R ($p < 0.01$). Addition of energy intake to these models did not change the results presented and the model R^2 increased by <1%. The multivariate model excluded respondents missing information on any covariate, therefore n = 8660.

HEI = Healthy Eating Index, RFS = Recommended Foods Score from 24-hour dietary recall, DDS-R = Dietary diversity score for recommended foods.

gm for beverages. For recommended foods reported more than once, the criterion for minimum amount was applied after summing all mentions of a food. Finally, several mentions of a recommended food in a recall contributed only one point to the score.

Dietary Diversity Score (DDS-R). The DDS as previously reported considers whether or not any food from each of the five major food groups was reported in the recall, with each food group contributing one point to the overall score, for a total of 5 [9]. For this study, we modified the previously published DDS by consideration of only those foods that are currently recommended in dietary guidance from each of the five major food groups. Accordingly, we evaluated each recall for whether a recommended food was mentioned from each of the five major food groups. Any mention of a recommended food from the fruit, vegetable, meat, dairy and grain in amounts meeting or exceeding the minimum amounts threshold mentioned above was considered to contribute one point to the score, for a maximum of five. Mixed dishes meeting the recommended criteria contributed component food group mentions to the score.

Biomarkers

The biomarkers available in the NHANES III public release data file included established, and emerging biomarkers of risk of cardiovascular disease, diabetes, and obesity: body mass index, systolic and diastolic blood pressure, serum total cholesterol, low density lipoprotein (LDL) cholesterol, high density lipoprotein (HDL) cholesterol, serum triglycerides, plasma glucose, serum insulin, glycated hemoglobin, serum C-peptide, lipoprotein (a), apolipoprotein AI and B, homocysteine, plasma fibrinogen, C-reactive protein, and leptin [14, 15]. Finally, we examined biomarkers of dietary exposure: serum vitamin C, serum vitamin E, serum folate, and the carotenoids—beta carotene, alpha carotene, lutein/zeaxanthin, beta cryptoxanthin,

Table 2. Weighted Percentage of Respondents in the Highest Category of Each Dietary Pattern Index by Categories of Socioeconomic and Life-Habit Variables, Disease Free Adults Aged ≥20 y, NHANES III, 1988–1994

	All	HEI 4th Quartile	RFS ≥5	DDS-R 4–5
n	8719	1998	2823	1775
% women	51.1 ± 0.7	57.8 ± 2.0	53.3 ± 1.4	53.6 ± 1.6
% aged ≥50 y	25.9 ± 1.1	39.2 ± 2.3	35.2 ± 1.7	37.9 ± 1.9
% Non-Hispanic White	77.2 ± 1.3	82.1 ± 1.6	82.1 ± 1.5	84.4 ± 1.5
% <12 y education	21.1 ± 1.1	15.1 ± 1.3	14.8 ± 1.0	15.1 ± 1.4
% Current smokers	29.8 ± 1.0	15.5 ± 1.6	17.8 ± 1.3	15.4 ± 1.5
% reporting no alcohol	39.8 ± 1.4	40.6 ± 2.1	39.2 ± 1.9	40.7 ± 2.1
% BMI ≥30	16.7 ± 0.8	13.9 ± 1.4	14.0 ± 1.1	12.9 ± 1.4
% no recreational physical activity/week	19.0 ± 0.9	14.1 ± 1.1	13.9 ± 1.2	13.4 ± 1.1

HEI = Healthy eating index, (highest quartile (≥73.0), RFS = Recommended Foods Score from 24-hour dietary recall, (highest score category = ≥5), DDS-R = Dietary diversity score for recommended foods, (highest score category = 4 and 5).

and lycopene. For serum triglycerides, plasma glucose, serum c-peptide, and insulin, respondents reporting <9 hours of fasting before phlebotomy were excluded.

Statistical Analyses

All statistical analyses were performed using SAS [16], and software designed for analysis of survey data (SUDAAN) [17]. This software generates variance estimates that are corrected for multi-stage stratified cluster probability design of complex surveys. Sample weights provided by the NCHS to correct for differential probabilities of selection, non-coverage, and non-response were used in all analyses to obtain point estimates.

We computed the least square mean and standard error of each score variable by selected socio-demographic and lifehabit characteristics from multivariate regression models. The association of each serum or plasma analyte with each dietary index was examined using linear regression models to adjusted for a number of covariates. All covariates included in the various multiple regression models were decided apriori based on known relationships of biomarkers with socio-demographic, and lifestyle factors, and included: gender, age, race (non-Hispanic White, non-Hispanic Black, Hispanic, other), years of education (<12, 12, >12), smoking status (never, former, current), level of weekly recreational physical activity (none, 1–2 times/week, >2 times/week), body mass index (<25, 25–30, >30), alcohol intake (none, ≤1, >1–≤2, >2 drinks/day), hours of fasting, supplement use in the 24 hours before phlebotomy, and supplement use in the past month. The multiple regression models for examining the independent association of dietary indexes with body mass index and blood pressure included all of the above variables except hours of fasting, supplement use in the past 24 hours before phlebotomy, supplement use in the past month. The and mean of each biomarker was obtained from covariate adjusted models by approximate quartiles of each dietary pattern index. To examine the trends in biomarker concentration, the dietary pattern index variables were also modeled as continuous variables. The Pearson's correlation method was used to examine the association of each diet index variable with energy, macro and micronutrient intake, using the NCHS recommended sample weights.

From the second dietary recall obtained from the second exam subsample for NHANES III, we computed within- and between-person components of variance for each type of dietary pattern index, using the varcomp procedure available in SAS.

Table 3. Correlation (Pearson's r) of Dietary Pattern Indexes with Dietary Energy and Nutrient Intake Derived from 24-Hour Recall, Weighted with Sample Weights, Disease-Free Adults Aged ≥20 y, NHANES III, 1988–1994

	HEI	RFS	DDS-R
RFS	0.57	1.0	0.74
DDS-R	0.57	0.74	1.0
Energy (kcals)	0.01[1]	0.06	0.01[1]
Protein (g)	0.02[1]	0.13	0.11
Fat (g)	−0.26	−0.003[1]	−0.07
Energy from fat (%)	−0.54	−0.14	−0.21
Saturated fat (g)	−0.31	−0.05	−0.09
Energy from sat fat (%)	−0.54	−0.20	−0.21
Carbohydrate (g)	0.22	0.11	0.10
Fiber (g)	0.36	0.42	0.34
Vitamin E (mg)	0.07	0.20	0.13
Vitamin C (mg)	0.35	0.42	0.30
Vitamin B-6 (mg)	0.27	0.36	0.31
Folate (μg)	0.29	0.38	0.32
Carotene (RE)	0.20	0.31	0.19
Vitamin A (RE)	0.14	0.25	0.18
Calcium (mg)	0.07	0.17	0.17
Sodium (mg)	−0.10	0.03	−0.002[1]
Magnesium (mg)	0.23	0.35	0.29
Potassium (mg)	0.24	0.40	0.29

HEI = Healthy eating index, RFS = Recommended Foods Score from 24-hour dietary recall, DDS-R = Dietary diversity score for recommended foods.

[1] NS ($p > 0.05$). For all other correlations mentioned in the table, $p < 0.0001$, (n = 8719).

Table 4. Least Square Mean ± SE[1] of Cardiovascular Disease Biomarkers by Categories of Dietary Pattern Indexes, Disease Free Adults Aged ≥20 y, NHANES III, 1988–1994

	Categories of dietary pattern index				$\beta \pm SE^2$	p (trend)[3]
	C1	C2	C3	C4		
HEI	≤54.5	54.6–63.6	63.7–72.9	>72.9		
N	2256	2253	2212	1998		
RFS	0–1	2	3–4	5–20		
N	1842	1465	2589	2823		
DDS-R	0–1	2	3	4–5		
N	2511	2390	2043	1775		
Systolic blood pressure (mm Hg) n = 8647						
HEI	117.9 ± 0.3	117.9 ± 0.4	117.9 ± 0.4	117.4 ± 0.4	−0.01 ± 0.01	0.5
RFS	118.0 ± 0.4	118.8 ± 0.5	117.8 ± 0.3	117.2 ± 0.3	−0.14 ± 0.06	0.02
DDS-R	118.4 ± 0.4	118.4 ± 0.3	117.4 ± 0.4	116.8 ± 0.4	−0.44 ± 0.01	0.005
Diastolic blood pressure (mm Hg) n = 8646						
HEI	73.1 ± 0.2	73.2 ± 0.3	72.9 ± 0.3	72.7 ± 0.3	−0.01 ± 0.01	0.3
RFS	73.1 ± 0.3	73.5 ± 0.3	72.8 ± 0.3	72.7 ± 0.3	−0.11 ± 0.04	0.03
DDS-R	73.3 ± 0.3	73.3 ± 0.3	72.7 ± 0.4	72.3 ± 0.3	−0.28 ± 0.11	0.02
Body mass index kg/m^2 n = 8474						
HEI	26.0 ± 0.2	25.7 ± 0.2	25.7 ± 0.2	25.0 ± 0.2	−0.03 ± 0.01	0.0003
RFS	26.1 ± 0.2	26.0 ± 0.2	25.7 ± 0.2	25.1 ± 0.1	−0.18 ± 0.03	<0.00001
DDS-R	26.0 ± 0.2	25.9 ± 0.2	25.6 ± 0.04	24.8 ± 0.1	−0.38 ± 0.06	<0.00001
Serum triglycerides mmol/L n = 3651[4]						
HEI	1.34 ± 0.04	1.31 ± 0.04	1.39 ± 0.04	1.42 ± 0.04	0.003 ± 0.002	0.1
RFS	1.43 ± 0.07	1.32 ± 0.05	1.36 ± 0.03	1.35 ± 0.03	−0.005 ± 0.008	0.4
DDS-R	1.41 ± 0.06	1.36 ± 0.03	1.32 ± 0.04	1.36 ± 0.04	−0.004 ± 0.017	0.7
Serum total cholesterol mmol/L n = 8071						
HEI	5.17 ± 0.04	5.16 ± 0.03	5.12 ± 0.43	5.12 ± 0.03	−0.002 ± 0.001	0.2
RFS	5.19 ± 0.04	5.19 ± 0.05	5.15 ± 0.03	5.09 ± 0.03	−0.012 ± 0.005	0.02
DDS-R	5.21 ± 0.04	5.18 ± 0.04	5.09 ± 0.04	5.07 ± 0.03	−0.287 ± 0.071	0.0006
Serum low-density cholesterol mmol/L n = 3611						
HEI	3.29 ± 0.05	3.21 ± 0.05	3.14 ± 0.04	3.18 ± 0.05	−0.003 ± 0.002	0.05
RFS	3.26 ± 0.05	3.31 ± 0.06	3.17 ± 0.04	3.15 ± 0.04	−0.012 ± 0.007	0.08
DDS-R	3.26 ± 0.05	3.21 ± 0.04	3.16 ± 0.05	3.18 ± 0.04	−0.018 ± 0.015	0.2
Serum high-density lipoprotein cholesterol mmol/L n = 8032						
HEI	1.32 ± 0.01	1.36 ± 0.02	1.33 ± 0.01	1.28 ± 0.01	−0.001 ± 0.001	0.02
RFS	1.31 ± 0.01	1.34 ± 0.02	1.33 ± 0.02	1.32 ± 0.01	0.000 ± 0.002	0.06
DDS-R	1.32 ± 0.01	1.34 ± 0.01	1.33 ± 0.01	1.30 ± 0.01	−0.006 ± 0.005	0.2
Serum Lipoprotein (a) g/L n = 4083						
HEI	0.19 ± 0.01	0.19 ± 0.01	0.22 ± 0.01	0.22 ± 0.01	0.001 ± 0.000	0.03
RFS	0.18 ± 0.01	0.20 ± 0.01	0.22 ± 0.01	0.22 ± 0.01	0.002 ± 0.001	0.3
DDS-R	0.18 ± 0.01	0.22 ± 0.01	0.21 ± 0.01	0.22 ± 0.01	0.009 ± 0.003	0.02
Serum apolipoprotein A1 g/L n = 3954						
HEI	1.44 ± 0.01	1.44 ± 0.01	1.43 ± 0.01	1.41 ± 0.01	−0.000 ± 0.000	0.1
RFS	1.42 ± 0.01	1.42 ± 0.01	1.46 ± 0.01	1.42 ± 0.01	−0.001 ± 0.001	0.3
DDS-R	1.43 ± 0.01	1.45 ± 0.02	1.43 ± 0.01	1.42 ± 0.01	−0.004 ± 0.004	0.3
Serum apolipoprotein B g/L n = 3968						
HEI	1.03 ± 0.01	1.01 ± 0.01	0.99 ± 0.01	1.01 ± 0.01	−0.000 ± 0.004	0.3
RFS	1.01 ± 0.01	1.03 ± 0.01	1.01 ± 0.01	1.01 ± 0.01	−0.001 ± 0.002	0.5
DDS-R	1.03 ± 0.01	1.02 ± 0.01	0.99 ± 0.01	1.00 ± 0.01	−0.009 ± 0.004	0.06
Serum homocysteine umol/L n = 3605						
HEI	9.87 ± 0.25	9.92 ± 0.33	9.51 ± 0.21	8.90 ± 0.21	−0.032 ± 0.10	0.003
RFS	10.09 ± 0.41	9.60 ± 0.34	9.68 ± 0.28	9.10 ± 0.20	−0.172 ± 0.04	0.0002
DDS-R	9.85 ± 0.31	9.54 ± 0.19	9.78 ± 0.39	8.89 ± 0.23	−0.261 ± 0.11	0.02
Plasma fibrinogen g/L n = 3884						
HEI	2.94 ± 0.03	2.92 ± 0.04	2.88 ± 0.04	2.92 ± 0.04	−0.000 ± 0.001	0.7
RFS	2.90 ± 0.04	2.95 ± 0.05	2.94 ± 0.04	2.89 ± 0.04	−0.009 ± 0.007	0.02
DDS-R	2.93 ± 0.03	2.91 ± 0.04	2.87 ± 0.04	2.92 ± 0.04	−0.000 ± 0.016	0.9
Serum C-reactive protein mg/dL n = 8029						
HEI	0.39 ± 0.02	0.34 ± 0.01	0.35 ± 0.01	0.33 ± 0.01	−0.001 ± 0.000	0.04
RFS	0.37 ± 0.03	0.37 ± 0.02	0.36 ± 0.01	0.33 ± 0.01	−0.007 ± 0.003	0.02
DDS-R	0.39 ± 0.02	0.35 ± 0.01	0.34 ± 0.01	0.32 ± 0.01	−0.018 ± 0.008	0.04

(*Table continues*)

Table 4. Continued

	Categories of dietary pattern index				$\beta \pm SE^2$	p (trend)^3
	C1	C2	C3	C4		
Serum leptin Fg/L n = 3435						
HEI	10.34 ± 0.36	10.25 ± 0.21	10.18 ± 0.32	10.18 ± 0.37	0.004 ± 0.01	0.8
RFS	9.93 ± 0.33	11.20 ± 0.55	10.38 ± 0.29	9.90 ± 0.26	−0.071 ± 0.07	0.3
DDS-R	10.27 ± 0.32	10.47 ± 0.32	10.40 ± 0.35	9.78 ± 0.30	−0.076 ± 0.12	0.5

[1] Least square means from regression models adjusted for multiple covariates. Models for SBP and DBP were adjusted for age, race/ethnicity, education, smoking, alcohol use, BMI, and activity. Models for BMI were adjusted for age (continuous), race/ethnicity, education, smoking, alcohol use, and activity, energy intake and trying to lose weight status. For all other variables, the multivariate models included age (continuous), race/ethnicity, education, smoking, alcohol use, BMI, recreational physical activity, hours of fasting, supplement use in past 24 hours, supplement use in past month.

[2] $\beta \pm$ SE and [3] p for trend with each biomarker as a continuous dependent variable.

[4] Excludes respondents with <9 hours of fasting before phlebotomy.

HEI = Healthy eating index, RFS = Recommended Foods Score from 24-hour dietary recall, DDS-R = Dietary diversity score for recommended foods.

RESULTS

The mean HEI, RFS, and DDS-R were, 63.75, 3.97, and 2.44, respectively, in the analytic sample (Table 1). Gender, age, education, smoking status, BMI, and level of recreational physical activity were significant predictors of each of the three dietary pattern indexes (Table 1). A higher proportion of respondents aged ≥50 y, with >12 y of education, and <25 BMI were in the highest approximate quartile of each index variable (Table 2). Approximately 7% of the population mentioned no recommended food in the 24-hour recall, 38% mentioned a low-fat or non-fat dairy product, 49% mentioned a fruit or fruit juice, 38% mentioned a whole grain, 42% mentioned a lean meat, poultry, fish or alternative, and 77% mentioned a vegetable that was not fried, creamed, or pickled. Only 5% mentioned at least one recommended food from all five major food groups on the recall day (data not shown).

The HEI and DDS-R were not correlated with dietary energy intake ($p > 0.05$); RFS showed a weak correlation ($r = 0.06$) (Table 3). The correlation of the three scores with the micronutrients examined was positive and of a comparable magnitude, with RFS being a somewhat stronger predictor than the other two scores. The HEI was a stronger correlate of dietary total and saturated fat, and carbohydrate relative to the other two indexes. The RFS and DDS-R were highly correlated ($r = 0.74$), and both were correlated with HEI ($r = 0.57$).

In multiple covariate adjusted regression models, all three scores were independent negative predictors of body mass index, serum homocysteine, serum C-reactive protein, plasma glucose, and hemoglobin A1C (Tables 4 and 5). The RFS and the DDS-R were independent negative predictors of systolic and diastolic blood pressure and total serum cholesterol (Table 4). The RFS also was a negative predictor of plasma fibrinogen. The HEI was a negative predictor of both LDL and HDL cholesterol. All indexes were strong positive predictors of serum concentrations of vitamins E and C, folate, and all carotenoids except lycopene (Table 6). The percentage of variance in each biomarker explained by the multivariate models containing each of the three dietary pattern indexes was of a comparable magnitude (data not shown). Addition of energy intake to multivariate regression models did not change the results presented (data not shown).

The ratios of within-person to between-person components of variance for the three dietary pattern indexes are presented in Table 7. The lowest ratios (which indicate greater repeatability) were seen for RFS, and were generally lower in women than men.

DISCUSSION

The results show that relative to a complex index (HEI) derived from quantitative consideration of ten dietary variables, two relatively simple indexes (RFS and DDS-R) were as good or somewhat better predictors of a number of dietary, and disease risk biomarkers. Thus suggesting that HEI had no special advantage over the simpler indexes for assessing healthful dietary patterns from a 24-hour recall when predicting objective biomarkers as outcome.

In accord with other observational studies that have examined the association of dietary indexes or scores with BMI, we found all scores in the present study to be negative predictors of BMI [18]. We had also expected the three scores to be associated with blood pressure because they approximate the DASH dietary patterns [19]. The results for the association of RFS and DDS-R were consistent with this expectation. Surprisingly, however, the HEI was not a predictor of blood pressure. It is possible that the observed associations may reflect a somewhat stronger association of RFS and DDS-R with dietary protein and most micronutrients (except sodium). It is noteworthy that few observational studies have examined the association of diet pattern indexes with blood pressure. In a comparison of dietary patterns for predicting the risk of incident hypertension in women in the EPIC-POTSDAM study, few associations were found between hypertension risk and dietary patterns. Although an association with the third quartile of a DASH diet based score was reported, the trend of association of risk of hypertension and the DASH diet score was not significant [20].

Table 5. Least Square Mean ± SE[1] of Glycemic Biomarkers by Categories of Dietary Pattern Indexes, Disease Free Adults Aged ≥20 y, NHANES III, 1988–1994

	Categories of dietary pattern index				$\beta \pm$ SE[2]	p (trend)[3]
	C1	C2	C3	C4		
Plasma glucose mmol/L n = 4821[4]						
HEI	5.28 ± 0.02	5.24 ± 0.02	5.28 ± 0.04	5.14 ± 0.02	−0.004 ± 0.00	0.0008
RFS	5.27 ± 0.03	5.27 ± 0.04	5.27 ± 0.04	5.18 ± 0.03	−0.014 ± 0.01	0.03
DDS-R	5.25 ± 0.03	5.30 ± 0.05	5.22 ± 0.02	5.16 ± 0.02	−0.026 ± 0.01	0.05
Plasma hemoglobin A1C (%) n = 8159						
HEI	5.20 ± 0.02	5.21 ± 0.02	5.19 ± 0.02	5.17 ± 0.02	−0.001 ± 0.00	0.02
RFS	5.21 ± 0.03	5.20 ± 0.03	5.21 ± 0.02	5.16 ± 0.02	−0.009 ± 0.00	0.002
DDS-R	5.22 ± 0.02	5.21 ± 0.02	5.16 ± 0.02	5.16 ± 0.02	−0.019 ± 0.01	0.01
Serum insulin pmol/L n = 4792[4]						
HEI	54.78 ± 1.0	53.48 ± 1.4	56.42 ± 1.7	56.42 ± 1.7	0.018 ± 0.05	0.7
RFS	55.69 ± 2.3	53.81 ± 1.6	54.71 ± 1.3	54.69 ± 1.1	−0.196 ± 0.26	0.4
DDS-R	56.12 ± 1.7	53.79 ± 1.3	55.26 ± 1.1	53.83 ± 1.4	−0.366 ± 0.61	0.5
Serum C-peptide nmol/L n = 4809[4]						
HEI	0.62 ± 0.01	0.60 ± 0.01	0.61 ± 0.01	0.56 ± 0.01	−0.001 ± 0.00	0.01
RFS	0.62 ± 0.01	0.60 ± 0.02	0.59 ± 0.01	0.59 ± 0.01	−0.005 ± 0.00	0.07
DDS-R	0.63 ± 0.01	0.61 ± 0.01	0.59 ± 0.01	0.57 ± 0.01	−0.013 ± 0.01	0.04

[1] Least square means from models adjusted for multiple covariates. Models were adjusted for age, race/ethnicity, education, smoking, alcohol use, BMI, recreational physical activity, hours of fasting, supplement use in the 24 hours before phlebotomy, supplement use in past month.

[2] $\beta \pm$ SE and [3] p for trend with each biomarker as a continuous dependent variable.

[4] Excludes respondents with <9 hours of fasting before phlebotomy.

HEI = Healthy Eating Index, RFS = Recommended Foods Score from 24-hour dietary recall, DDS-R = Dietary diversity score for recommended foods.

Given the single measurement of dietary intake in the present study, we did not expect to find associations of serum lipids with the dietary pattern indexes. We had further expected that due to the stronger association of HEI (relative to the other two indexes) with dietary saturated fat, HEI would perform better for predicting serum lipid /lipoprotein profiles. A stronger association of HEI with dietary fat and saturated fat was expected since these two nutrients are components of the overall score. Although HEI was a negative predictor of LDL concentration, it is notable that HEI also had a negative association with HDL concentration. On the other hand, the RFS and DDS-R were far weaker predictors of dietary intake of total and saturated fat, but were independent negative predictors of serum total cholesterol. The reasons for these disparate associations are not clear. We note that Weinstein and colleagues have reported similar findings in a much larger sample of NHANES III which had no exclusions for known chronic disease or its pharmacologic treatment [21].

Few studies have examined the independent association of index based dietary patterns with the range of biomarkers that were examined in the present study. Generally, the associations of serum biomarkers of fruit and vegetable intake with index based patterns have been reported to be consistently positive [22–25]. Hann et al found HEI determined from 3-day diet records to be a positive predictor of serum carotenoids and vitamin C, but not serum folate and lycopene in 340 women [22]. Three studies have examined different versions of another complex quantitative index—the diet Quality Index or DQI in relation to dietary biomarkers [23–25]. Neuhouser derived DQI from a 122-item FFQ and found it to be related positively with serum vitamins C and E, and beta cryptoxanthin but not serum folate [23]. Gerber et al found a DQI adapted for the French diet to be a predictor of serum vitamin E, DHA, EPA, and beta carotene [24]. Newby et al also reported that plasma carotenoids and vitamin E were positive correlates, and serum cholesterol a negative correlate, of a revised DQI [25]. It is noteworthy that although the RFS and DDS-R are relatively simple indexes that do not require quantitative estimation of servings of foods beyond a minimum threshold amount, but were positive predictors of dietary biomarkers.

We could find no studies where the independent association of index based patterns with prothrombotic, proinflammatory, or glycemic biomarkers has been reported. Finally, we included known confounders of the association of dietary variables and biomarkers in our regression models, however, the possibility of residual confounding due to poorly measured or unknown confounders in an observational study such as this one, can not be excluded.

A number of studies where patterns were derived from factor or cluster analysis have also examined biomarkers and present a mixed picture. In an analysis of data from a subsample (n = 466 men) of the Health Professionals Study cohort, Fung et al found the pattern labeled as prudent (from factor analysis) to be an inverse predictor of serum homocysteine and insulin and a positive predictor of serum folate; however, fifteen other biomarkers of obesity and cardiovascular disease examined were unrelated with this pattern [26]. The pattern labeled western in this study was a positive predictor of

Table 6. Least Square Mean ± SE[1] of Biomarkers of Dietary Intake by Categories of Dietary Pattern Indexes, Disease Free Adults Aged ≥20 y, NHANES III, 1988–1994

	Categories of dietary pattern index				$\beta \pm$ SE[2]	p (trend)[3]
	C1	C2	C3	C4		
Serum vitamin C mmol/L n = 7814						
HEI	38.1 ± 1.2	41.0 ± 0.8	45.5 ± 1.0	48.6 ± 1.0	0.35 ± 0.03	<0.00001
RFS	36.9 ± 1.3	40.0 ± 1.2	42.5 ± 0.7	48.9 ± 1.0	1.73 ± 0.13	<0.00001
DDS-R	38.0 ± 1.3	41.6 ± 1.1	45.5 ± 1.0	48.9 ± 1.1	3.19 ± 0.36	<0.00001
Serum folate nmol/L n = 8098						
HEI	13.6 ± 0.3	13.8 ± 0.3	15.1 ± 0.3	17.1 ± 0.5	0.12 ± 0.01	<0.00001
RFS	13.2 ± 0.3	14.2 ± 0.4	14.3 ± 0.3	16.7 ± 0.4	0.59 ± 0.09	<0.00001
DDS-R	13.3 ± 0.3	14.1 ± 0.3	14.8 ± 0.4	17.9 ± 0.5	1.18 ± 0.13	<0.00001
Serum vitamin E μmol/L n = 7814						
HEI	25.2 ± 0.2	25.2 ± 0.2	25.9 ± 0.2	27.1 ± 0.3	0.07 ± 0.01	<0.00001
RFS	25.0 ± 0.3	25.2 ± 0.2	25.4 ± 0.2	27.0 ± 0.3	0.41 ± 0.10	0.0002
DDS-R	24.8 ± 0.2	25.4 ± 0.2	26.1 ± 0.2	27.4 ± 0.4	0.70 ± 0.10	<0.00001
Serum α-carotene μmol/L n = 7997						
HEI	0.072 ± 0.002	0.083 ± 0.002	0.093 ± 0.003	0.118 ± 0.004	0.001 ± 0.000	<0.00001
RFS	0.072 ± 0.003	0.077 ± 0.002	0.084 ± 0.002	0.114 ± 0.003	0.009 ± 0.000	<0.00001
DDS-R	0.073 ± 0.002	0.085 ± 0.002	0.092 ± 0.002	0.119 ± 0.004	0.012 ± 0.001	<0.00001
Serum β-carotene μmol/L n = 7997						
HEI	0.332 ± 0.009	0.359 ± 0.013	0.373 ± 0.010	0.441 ± 0.014	0.003 ± 0.000	<0.00001
RFS	0.326 ± 0.010	0.340 ± 0.009	0.354 ± 0.010	0.438 ± 0.008	0.022 ± 0.002	<0.00001
DDS-R	0.330 ± 0.008	0.357 ± 0.008	0.374 ± 0.011	0.454 ± 0.013	0.035 ± 0.004	<0.00001
Serum β-cryptoxanthin μmol/L n = 7997						
HEI	0.143 ± 0.003	0.158 ± 0.004	0.165 ± 0.003	0.196 ± 0.005	0.001 ± 0.000	<0.00001
RFS	0.139 ± 0.004	0.148 ± 0.004	0.162 ± 0.004	0.190 ± 0.004	0.009 ± 0.000	<0.00001
DDS-24H	0.142 ± 0.003	0.158 ± 0.004	0.172 ± 0.004	0.193 ± 0.006	0.014 ± 0.001	<0.00001
Serum lutein/zeaxanthin μmol/L n = 7997						
HEI	0.351 ± 0.006	0.367 ± 0.007	0.386 ± 0.008	0.411 ± 0.008	0.002 ± 0.000	<0.00001
RFS	0.335 ± 0.005	0.343 ± 0.009	0.370 ± 0.006	0.424 ± 0.008	0.016 ± 0.001	<0.00001
DDS-R	0.345 ± 0.003	0.372 ± 0.006	0.389 ± 0.008	0.413 ± 0.011	0.019 ± 0.004	<0.00001
Serum Lycopene μmol/L n = 7997						
HEI	0.440 ± 0.005	0.456 ± 0.006	0.443 ± 0.007	0.449 ± 0.007	0.000 ± 0.000	0.07
RFS	0.443 ± 0.007	0.433 ± 0.007	0.446 ± 0.007	0.456 ± 0.006	0.002 ± 0.001	0.04
DDS-R	0.443 ± 0.006	0.439 ± 0.007	0.442 ± 0.006	0.466 ± 0.007	0.006 ± 0.002	0.01

[1] Least square means from regression models adjusted for multiple covariates. For all dependent variables in the table, the multivariate models included age, race/ethnicity, education, smoking, alcohol use, BMI, recreational physical activity, hours of fasting, supplement use in 24 hours before phlebotomy, supplement use in past month. For serum vitamin E and carotenoids, serum cholesterol and triglycerides were also included.

[2] $\beta \pm$ SE and [3] p for trend with each biomarker as a continuous dependent variable.

HEI = Healthy eating index, RFS = Recommended Foods Score from 24-hour dietary recall, DDS-R = Dietary diversity score for recommended foods.

HDL cholesterol, LDL cholesterol, homocysteine, insulin, and c-peptide. Kerver et al derived two patterns (western and American healthy) from factor analysis of the FFQ from the NHANES III. American healthy-showed no association with any examined biomarker, the western pattern showed a positive association with three glycemic biomarkers, C-peptide, insulin and glycated hemoglobin [27]. Recently, Newby et al found a healthy cluster and factor to be predictors of serum triacylglycerol concentration, but not total, LDL or HDL cholesterol [28]. This brief review of studies that have examined biomarker and pattern associations suggests that the dietary pattern indexes examined in this study perform somewhat better at predicting biomarkers of disease than several other patterns reported in the literature. However, because index-based patterns (as opposed to patterns derived from exploratory factor or cluster analyses) reflect known diet and disease associations, their stronger associations with biomarkers are not surprising.

We note that the three indexes reported here were derived from a single 24-hour recall with its well known limitations for measuring usual dietary intake [29]. Although the association of dietary pattern indexes with dietary biomarkers provides an objective validation of the self-reported intake, considerable dietary reporting errors are known to be present in the NHANES III data and probably contribute to misclassification of respondents [30]. Apart from random or systematic errors in self-reported intake, given the ratios of within to between-person components of variance for the three indexes (especially the HEI and the DDS-R), it is likely that with-in person variability in intake contributed to attenuation of estimates of association.

Table 7. The Ratio of within- to between-Person Components of Variance for the Three Dietary Patterns Indexes, Disease Free Adults Aged ≥20 y with Two Acceptable Dietary Recalls, NHANES III, 1988–1994

	HEI-C	RFS	DDS-R
All (n = 617)	1.26	0.89	1.12
Men (n = 299)	1.43	1.05	1.00
Women (n = 318)	1.13	0.79	1.24

HEI-C = Healthy eating index computed from first and second recall, RFS = Recommended Foods Score from 24-hour dietary recall, DDS-R = Dietary diversity score for recommended foods.
The components of variance were determined from two non-consecutive, in-person 24-hour dietary recalls.

To our knowledge, this is the first study to present estimates of within-person and between-person variance in the three dietary pattern indexes reported here. Generally, the estimates of the ratio of within-person to between-person variance are smaller than other published variance estimates for most nutrients and food groups [31]. We note however, that our estimates are derived from only two dietary measurements and our methods are sensitive to variability in only the total score of each index. Variability in food selection which may not result in a change in the overall score is not captured by our methods.

An assumption inherent in all studies that examine the association of index based patterns with an outcome is that a given less than perfect score should relate similarly to an outcome. However, an identical numerical score on an index based pattern may reflect many different dietary profiles. For example, a score of 70 on the HEI can result from many different combinations of the ten contributing components, a score of four on the RFS can result from mention of four recommended foods from one or more food groups in several different combinations, and a score of 3 on the DDS-R can be due to omission of any two of the five food groups. Thus, it is likely that subjects with similar scores may not show a similar association with an outcome further contributing to attenuation of the association.

In conclusion, the two relatively simple dietary pattern indexes—the RFS and DDS-R—performed as well if not better than the HEI for predicting serum nutrient concentrations and biomarkers of disease risk.

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